INCOME MAXIMIZING ON CONCURRENT RATIO-INTERVAL SCHEDULES OF REINFORCEMENT

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Three experiments examined the effect of food availability on pigeons' choice behavior under concurrent schedules of reinforcement. In Experiment 1, 3 pigeons earned their daily food ration by choosing, in 30-min sessions, between concurrent variable-ratio 30 variable-interval 40-s schedules. Food presentations during both schedules lasted 2 or 12 s, depending upon the condition. Relative variable-ratio response rate was inversely related to hopper duration. In Experiment 2, 4 pigeons received their daily feeding by responding on the same schedule pair as in Experiment 1 (with 4-s food presentations) in sessions that varied in length from 10 to 30 min, depending on the condition. The length of a vertical slit projected on a response key increased with time so that "passage of time" might be more easily discriminable. As session duration decreased, relative variable-ratio response rate increased. In Experiment 3, 4 pigeons chose between two variable-interval 40-s schedules. One schedule operated without regard to the schedule selected, whereas the other operated only when the subject responded in its presence (dependent). Although these schedules had the same feedback function, preference for the dependent variable interval increased as session duration decreased from 30 to 10 min. The preference changes in these studies reveal the operation of an income-maximizing process in choice.

Key words: economics, concurrent variable-ratio variable-interval schedules, maximizing, key peck, pigeons

In a study by Herrnstein and Heyman (1979), pigeons chose between concurrent variable-ratio (VR) variable-interval (VI) schedules of reinforcement. Across conditions, they varied the values of these schedules and found that pigeons' concurrent performances were well described by the generalized matching equation:

$$B_1/B_2 = a(R_1/R_2)^b \qquad (1)$$

where B refers to behavior either in the form of responses or time allocation, R refers to reinforcers, a and b are parameters, and the subscripts identify the choice alternatives (see Baum, 1974).

Although pigeons' choice behavior conformed with the predictions of this matching equation, it was incompatible with maximizing the rate of reinforcement. To maximize reinforcement rates on these schedules, most of an animal's choices should be to the VR schedule with only occasional, brief switches

to the VI. Such a strategy uses to advantage the differences between VR and VI reinforcement feedback functions. On VR schedules, reinforcement rate increases linearly with increases in response rate, whereas on VI schedules this function is negatively accelerated. As a consequence, marginal increases in response rate are associated with greater increases in reinforcement rate on VR than VI schedules (Prelec, 1982). That animals match without following the maximizing strategy outlined above was interpreted by Herrnstein and Heyman (1979) as establishing the primacy of matching over maximizing in choice.

Although the Herrnstein and Heyman (1979) study demonstrates that animals do not maximize their rates of reinforcement in choice, it remains possible that some other dimension of reinforcement is maximized, but their choice test is insensitive to it. One possibility recently raised by Sakagami, Hursh, Christensen, and Silberberg (1989) is that hungry animals maximize not their *income flow* (rate of food reinforcement) but their *income level* (aggregate amount of food obtained per day).

In the Herrnstein and Heyman (1979) experiment, sessions terminated after 60 reinforcers, and daily food intake was adjusted to

ensure that animals were maintained at 80% of their free-feeding weights. As a consequence, income level was held constant and was independent of income flow. Because maximizing income flow did not affect income level, income-level maximizing was unrealizable, permitting alternative processes to govern choice.

One way to test for income maximizing on concurrent VR VI schedules is to alter Herrnstein and Heyman's (1979) design so that income level can change with changes in choice. Toward this end, pigeons in the first experiment of our study chose between VR and VI schedules, earning their entire daily food ration during an experimental session of fixed duration. Food availability was changed across conditions by varying the number of seconds the food hopper was presented during reinforcement. As the duration of the hopper presentations was decreased, animals could defend their food intake only by increasing the frequency with which hopper presentations occurred. This meant that response rates to both schedules should increase. However, because changes in overall response rate under ratio schedules typically result in greater changes in reinforcement rate than that resulting from the same change in response rate under an interval schedule, an animal optimizing its food intake should increase responding to the VR schedule more than to the VI. In other words, income-level maximizing predicts an overall increase in behavioral output and an inverse relation between hopper duration and the relative VR response rate.

EXPERIMENT 1

METHOD

Subjects

Three adult White Carneau pigeons began the experiment at their free-feeding weights. All birds had substantial and varied experience responding to different schedules of reinforcement.

Apparatus

Separate but identical sound-attenuating chambers, measuring 34.3 by 30.5 by 33 cm, served as the experimental space for each subject. With the exception of the stainless steel front panel, all walls were made of galvanized

steel. Centered on the front panel, 5.5 cm above the wire mesh floor, was a hopper aperture 5.5 by 5 cm. A houselight was positioned directly above the hopper aperture, 26.2 cm above the chamber floor. Three Lehigh Valley Electronics response keys (2.54 cm diameter), spaced 7.6 cm apart center to center, were located 21 cm above the chamber floor. Each key was transilluminated by an Industrial Electronics Engineers multistimulus projector. A PDP-8/e® computer controlled and recorded events using SuperSKED® software.

Procedure

Animals were exposed without preliminary training to the following choice procedure in Phase 1: Each session began with the illumination of the left key with white light, and, with equal likelihood, the right key with either red or green light. When red, a VR-30 schedule was associated with the right key; when green, a VI 40-s schedule was assigned to this key. A response on the left (white) key switched the right-key color and initiated a 1.5-s changeover delay (COD). During this period, right-key responses had no scheduled consequences. In addition, left-key responses had no scheduled consequences unless at least one right-key response occurred following a left-key response. The VR and VI reinforcement distributions were composed of 12 different values and were determined by the Fleshler and Hoffman (1962) formulation.

In Phases 1 and 3, the hopper duration for both schedules was 2 s, whereas in Phase 2 the hopper duration was increased to 12 s. The VR schedule was signaled by a blue and green light during Phases 2 and 3, respectively, and the VI schedule was correlated with white and blue light, respectively, during these phases. All sessions lasted 30 min, excluding hopper times. Subjects earned their entire daily food ration during the session. Each phase was in effect for 21 consecutive days. Results are based on the mean of the last three sessions of each phase for each subject.

RESULTS

Table 1 presents the number of responses to a schedule, the time allocated to a schedule, the number of reinforcers each schedule provided, the number of changeovers between schedules, and body weight averaged over the last three sessions of a phase for each subject.

Table 1

Summary data: means and standard error of the mean (in parentheses) computed over the last three sessions for each condition.

Subject	Condition	Responses		Time allocation (min)		Reinforcers		Change-overs	Body weight (g)
		VR	VI	VR	VI	VR	VI		
0	2 s	2,289 (134)	655 (12)	18.6 (0.9)	11.4 (0.9)	74 (6)	33 (1)	171 (4)	492 (1.7)
	2 s[a]	2,352 (133)	1,000 (66)	18.7 (0.3)	11.3 (0.3)	77 (4)	37 (1)	235 (3)	508 (2.1)
	12 s	484 (63)	290 (44)	12.7 (2.3)	17.3 (2.3)	15 (3)	21 (2)	9 (2)	515 (0.3)
1	2 s	126 (31)	1,169 (45)	3.7 (0.7)	26.3 (0.8)	5 (1)	38 (0)	53 (9)	415 (2.0)
	2 s[a]	400 (13)	947 (33)	8.9 (0.5)	21.1 (0.5)	16 (1)	40 (2)	127 (5)	481 (1.7)
	12 s	13 (4)	415 (50)	2.1 (0.8)	27.9 (0.8)	0 (0)	38 (2)	19 (5)	569 (3.0)
2	2 s	1,888 (38)	1,066 (24)	17.6 (0.4)	12.4 (0.4)	62 (1)	36 (1)	219 (23)	513 (2.1)
	2 s[a]	1,658 (49)	661 (35)	18.5 (0.3)	11.5 (0.3)	54 (0)	38 (2)	274 (18)	563 (6.7)
	12 s	171 (65)	430 (97)	10.1 (2.0)	19.9 (2.0)	5 (1)	28 (3)	52 (12)	647 (2.9)

[a] Replication.

For all subjects, between-condition increases in hopper duration led to increases in body weights and decreases in total responses, reinforcers, and changeovers.

Figure 1 presents the relative frequency of VR responding, time allocation, and reinforcement for each phase of the experiment for individual subjects, as well as the mean across subjects. For all subjects, all proportions were inversely related to hopper duration.

Figure 2 presents each schedule's local response rate (responses to a schedule divided by time allocated to that schedule) as a function of the duration of access to the grain magazine for each bird and the average across birds. Except for Bird 1 and the 12-s hopper-duration condition for Bird 2, VR response rates tended to be higher than VI rates.

DISCUSSION

In this experiment, the response rate to each schedule and the relative VR response rate varied inversely with hopper duration. Each of these findings is predicted by income maximizing. The response-rate prediction follows from the fact that as hopper duration increases, fewer hopper presentations are needed to maintain body weight. Animals can increase the efficiency (and lower the cost) of producing these hopper presentations by increasing their average interresponse times (IRTs). If animals are maximizing income, a shift in preference toward the VI should attend any lowering of response rate. This prediction is based on the fact that, at the margin, longer IRTs are more productively emitted on VI than on VR schedules. Thus, increasing the hopper duration should lower the relative VR response rate, the very result obtained.

Although all subjects increased their responding to the VR schedule when hopper duration was reduced, Bird 1 maintained its preference for the VI over the VR in all conditions. This VI preference is surprising in that it contributed to weight loss (seen during the 2-s hopper condition) and raises the prospect that although income maximizing may operate in choice, additional processes insensitive to the relation between choice and aggregate food income are also present.

EXPERIMENT 2

In Experiment 1, VR and VI response rates and relative VR response rates were inversely related to income level. The present experi-
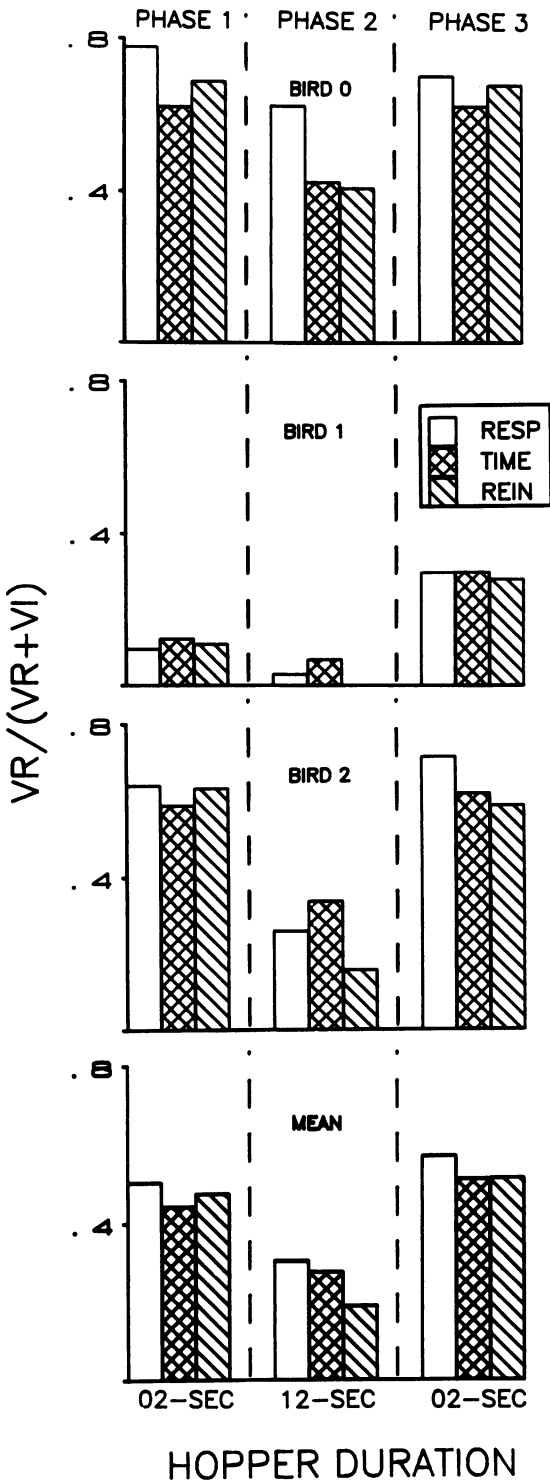
Fig. 1. Relative frequency of VR responding (open bars), time (cross-hatched bars), and reinforcement (diagonally hatched bars) as a function of reinforcer duration for each bird and averaged across subjects.
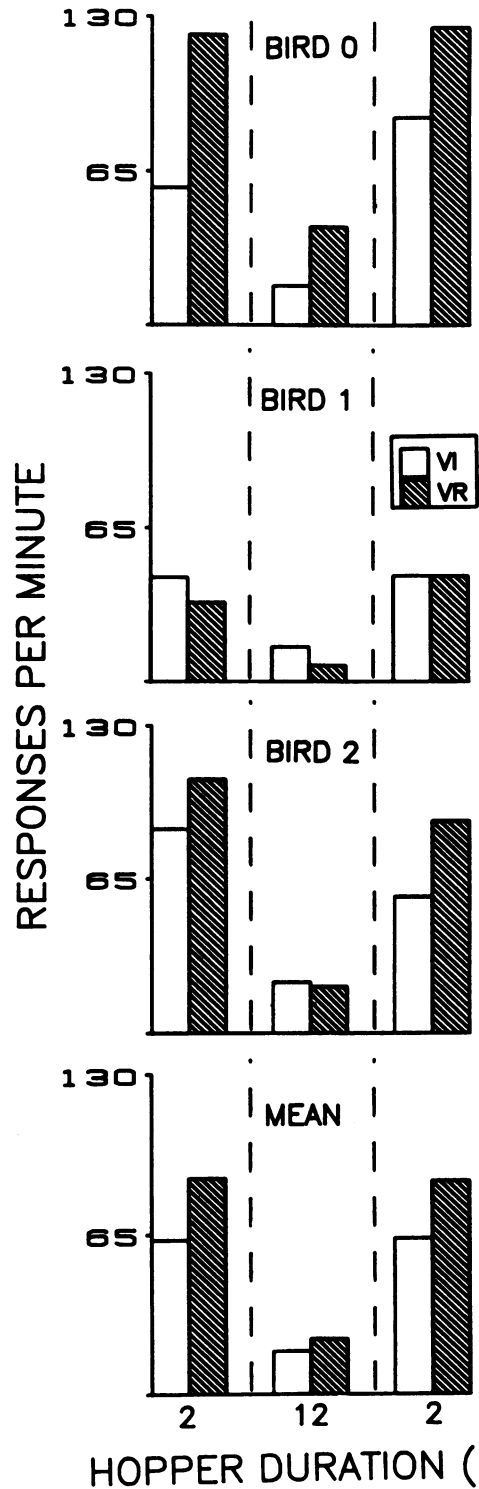
Fig. 2. Each schedule's local response rate as a function of hopper duration for each bird and averaged across subjects. Open bars represent VI response rates, and diagonally hatched bars represent VR response rates.

ment tested the generality of this finding by altering not the size of the reinforcer but the length of the session. To make sure that session duration served as a discriminable event, the length of a vertical line projected on a response key was used to define the portion of the session that had elapsed. According to income maximizing, any reduction in session length should lead to an increase in response rates, with most of the additional responding occurring to the VR schedule.

METHOD

Subjects

Four adult White Carneau pigeons began the experiment at their free-feeding weights. All birds had substantial and varied experience responding to different schedules of reinforcement.

Apparatus

A sound-attenuating chamber, measuring 35 by 31 by 33.5 cm, served as the experimental space. With the exception of the stainless-steel front panel, all walls were made of aluminum. Centered on the front panel, 5.5 cm above the wire mesh floor, was a hopper aperture (6 by 6 cm). Two houselights were positioned 30.5 cm above the grid floor, one in each corner of the panel, and spaced 22 cm apart. The houselights could be illuminated separately, the left with green light and the right with red light.

Two response keys, 2.54 cm in diameter and spaced 13 cm apart measured center to center, were located 18.5 cm above the chamber floor. The left response key was dark except for a horizontal slit (0.3 cm wide by 2.54 cm long) that could be transilluminated by a white light. The right key had an identical slit that was projected vertically. At the start of the experiment, the vertical slit was a square (0.3 cm). As time in the session passed, a black triangular shade positioned between the key and the light bulb lengthened the vertical slit until, at session's end, it bisected the key ("added clock"; Ferster & Skinner, 1957).

Procedure

Each session began with the illumination of the left and right keys with white light, and, with equal likelihood, illumination of the left green houselight or right red houselight. When the red houselight was illuminated, a VR 30 schedule was associated with the right key; when the green houselight was illuminated, a VI 40-s schedule was assigned to that key. Each left-key response switched the schedule in effect on the right key, the color of the houselight illumination, and initiated a 1.5-s COD. For both schedules, reinforcement consisted of 4 s of access to mixed grain.

Table 2 presents the order of experimental conditions and the number of sessions each subject was exposed to a condition. Each condition ended after 25 sessions except when (in the judgment of the experimenter) choice ratios were unstable. Results are based on the mean of the last three sessions of each condition for each subject. All other features of the procedure were the same as in Experiment 1.

RESULTS

Table 2 also presents, for each subject and schedule, the local response rate (responses to a schedule divided by time in the presence of that schedule), overall response rate (total schedule responses divided by total session time), changeover rate, local reinforcement rate, overall reinforcement rate, and body weight. These data show that, as session duration decreased, (a) response rates increased, typically with a greater increase in responding to the VR schedule, (b) local and overall rates of reinforcement increased, and (c) body weight decreased.

Figure 3 presents the relative rate of VR responding, time allocation, and reinforcement for 4 subjects individually and averaged across subjects as a function of session duration. Increasing session duration produced a relative decrease in VR responding, time allocation, and reinforcement.

DISCUSSION

These results, in conjunction with those from Experiment 1, show that reductions in food availability, whether produced by shortening the hopper duration or the length of the session, cause response rates to both VR and VI schedules to increase, with the increase in VR responding being greater than the increase in VI responding. Because marginal increases in response rate on VI schedules generally produce fewer additional reinforcers than do marginal VR rate increases, an organism attempting to optimize food intake should allocate more

Table 2

Summary data: means and standard error of the means (in parentheses) over last three sessions for each condition and number of sessions and order of conditions.

| Subject	Session duration (min)	Responses/min Local VR	Responses/min Local VI	Responses/min Overall	Change-overs	Reinforcers/min Local VR	Reinforcers/min Local VI	Reinforcers/min Over-all	Body weight (g)	Number of sessions	Order
21	10	77.4 (5.5)	51.0 (1.5)	61.6 (0.9)	6.7 (0.6)	2.9 (0.7)	2.1 (0.3)	2.4 (0.3)	480 (1.7)	25	4
	10[a]	72.2 (6.0)	49.0 (4.0)	55.5 (2.7)	3.4 (0.4)	3.0 (0.9)	1.8 (0.3)	2.2 (0.4)	493 (1.5)	25	6
	15	59.9 (7.3)	38.8 (3.1)	50.0 (5.1)	6.9 (0.8)	2.1 (0.2)	2.5 (0.2)	2.3 (0.1)	508 (2.5)	25	3
	20	68.5 (2.0)	34.5 (2.8)	47.2 (0.9)	2.6 (0.5)	2.5 (0.3)	2.2 (0.2)	2.3 (0.2)	512 (1.0)	25	2
	30	24.9 (24.9)	41.6 (2.5)	42.9 (3.5)	0.2 (0.1)	0.8 (0.8)	1.6 (0.9)	1.6 (0.1)	505 (0.9)	50	1
	30[a]	49.9 (3.6)	24.3 (2.2)	27.5 (5.1)	1.3 (0.3)	1.7 (0.6)	1.6 (0.4)	1.6 (0.1)	522 (0.6)	35	5
22	10	60.5 (2.4)	53.8 (1.7)	55.9 (1.1)	3.4 (1.3)	1.9 (1.0)	2.3 (0.5)	2.2 (0.3)	394 (1.0)	25	4
	10[a]	61.9 (1.4)	54.0 (2.6)	55.5 (2.2)	2.0 (0.9)	2.1 (0.2)	2.0 (0.4)	1.9 (0.3)	346 (1.3)	25	6
	15	22.6 (8.1)	54.6 (5.0)	52.1 (6.8)	0.8 (0.7)	0.3 (0.3)	1.6 (0.1)	1.6 (0.1)	416 (0.8)	25	3
	20	35.2 (17.1)	59.2 (1.9)	58.9 (2.0)	0.1 (0.0)	1.2 (0.6)	1.6 (0.0)	1.6 (0.0)	429 (1.7)	25	2
	30	0.0 (0.0)	63.1 (1.2)	63.1 (1.2)	0.0 (0.0)	0.0 (0.0)	1.6 (0.1)	1.6 (0.1)	447 (1.1)	25	1
	30[a]	51.3 (4.4)	56.9 (2.3)	56.8 (2.3)	0.3 (0.1)	2.2 (0.8)	1.6 (0.0)	1.6 (0.0)	428 (0.4)	25	5
23	10	83.2 (0.2)	46.4 (0.9)	58.7 (1.9)	3.3 (0.3)	2.0 (0.4)	1.9 (0.2)	1.9 (0.2)	478 (2.7)	25	4
	10[a]	62.1 (3.3)	46.4 (1.4)	50.1 (1.7)	3.0 (0.6)	1.5 (0.8)	1.9 (0.2)	1.8 (0.4)	500 (0.5)	25	6
	15	59.5 (2.8)	44.7 (2.4)	51.0 (1.5)	2.6 (0.4)	2.2 (0.5)	2.2 (0.1)	2.2 (0.1)	524 (0.7)	25	3
	20	21.1 (13.5)	48.7 (1.2)	47.5 (0.7)	0.4 (0.1)	0.9 (0.9)	1.6 (0.3)	1.6 (0.0)	503 (1.0)	25	2
	30	4.6 (2.9)	38.4 (1.1)	38.2 (1.0)	0.1 (0.0)	0.0 (0.0)	1.6 (0.0)	1.6 (0.0)	528 (0.2)	25	1
	30[a]	34.3 (4.6)	37.5 (5.2)	37.0 (5.1)	1.8 (0.2)	1.2 (0.3)	1.6 (0.1)	1.5 (0.1)	587 (1.0)	35	5
24	10	51.4 (3.5)	86.6 (2.4)	80.1 (2.8)	2.8 (0.8)	1.8 (1.1)	2.1 (0.2)	2.1 (0.4)	446 (1.5)	25	4
	10[a]	60.3 (7.0)	61.0 (4.7)	62.5 (4.1)	4.5 (1.8)	1.5 (0.8)	2.2 (0.3)	2.0 (0.3)	478 (2.7)	25	6
	15	16.2 (2.5)	79.0 (2.5)	76.3 (4.0)	0.8 (0.4)	0.3 (0.3)	1.7 (0.1)	1.6 (0.1)	464 (2.6)	25	3
	20	9.2 (4.5)	67.9 (4.0)	67.1 (4.3)	0.2 (0.1)	0.0 (0.0)	1.6 (0.1)	1.6 (0.1)	513 (0.5)	25	2
	30	5.8 (1.3)	41.6 (3.4)	34.1 (5.3)	1.3 (0.5)	0.0 (0.0)	1.9 (0.2)	1.5 (0.1)	528 (0.2)	30	1
	30[a]	3.2 (0.0)	49.9 (1.9)	49.6 (1.8)	0.0 (0.0)	0.0 (0.0)	1.6 (0.1)	1.5 (0.1)	533 (0.5)	25	5

[a] Replication.
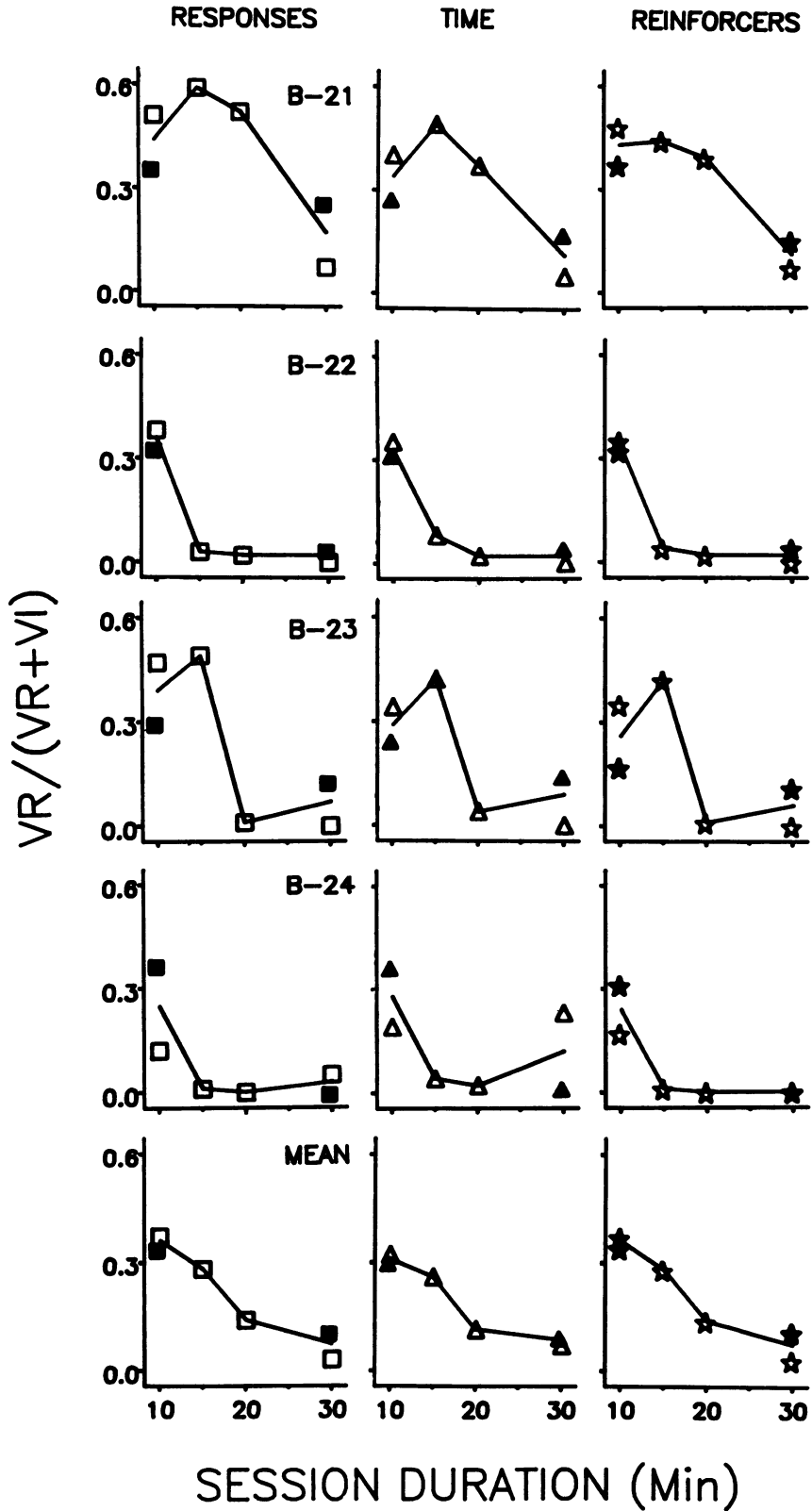
Fig. 3. Relative rate of VR responding (left column), time allocation (center column), and reinforcement (right column) for each subject (top four rows) and averaged across subjects (bottom row) as a function of session duration conditions. Initial determinations are represented by open symbols, and redeterminations are represented by closed symbols. Solid lines connect mean outcomes at each session duration.

of its additional behavior to the VR than to the VI schedule as food is less readily available. That this tendency is evident in Experiments 1 and 2 is consistent with the thesis that income maximizing operates in choice.

The results of Experiment 2 are clearer than those of Experiment 1 in showing that, although income maximizing is present in choice, other processes must also be present. On average, subjects in Experiment 2 preferred the VI schedule regardless of session duration and the effects of this preference on body weight.

The attribution of changes in choice to an income-maximizing principle in Experiments 1 and 2 is compromised, to some degree, by the possibility that alternative strength-based accounts can also produce these effects. One such account argues that reducing hopper duration or session length increases hunger. Hungrier organisms respond more rapidly than less hungry organisms (e.g., Clark, 1958). If organisms allocate these additional pecks in exactly the same proportion as when they were less hungry, they will, by virtue of each schedule's feedback function, receive disproportionately more reinforcers from the VR than from the VI schedule. If these organisms are attempting to match their choice ratios to their obtained reinforcer ratios (Herrnstein & Heyman, 1979), these additional reinforcers would produce a shift in preference toward the VR. Thus, arguing that deprivation elevates rates, and that organisms match, is sufficient to explain important features of the results from Experiments 1 and 2.

DeCarlo (1985; see also Heyman & Herrnstein, 1986) has developed a procedure that may enable selection between these alternative explanations of the results from Experiments 1 and 2. The important feature of his procedure is that it reproduces essential features of a concurrent VR VI schedule while keeping reinforcement rate independent of response rate. Responding to the changeover key switches the schedule in effect, whereas responding to the other key has no programmed consequences. When a particular schedule has been selected, its reinforcers are delivered independently of responding. The surrogate for the VI (called an independent variable time (VT) schedule) operates whether the animal has selected that schedule or its alternate. Any reinforcer assigned is delivered immediately if that schedule is in effect; if the alternate sched-ule is in effect, reinforcers are delivered after the COD has terminated following a change-over back to this schedule. The surrogate for the VR (called a dependent VT schedule) also assigns its reinforcers on the basis of time and delivers them without requiring a response. However, this schedule differs from an independent VT schedule in that it operates only when it has been selected.

To maximize income level in DeCarlo's (1985) procedure, subjects should spend most of their time in the presence of the dependent VT schedule, with only occasional brief shifts to pick up reinforcers that had been assigned by the independent VT schedule. This pattern of choice allocation maximizes reinforcement rate because it keeps both schedules running as much as possible. Contrary to the predictions of rate maximizing, a bias in favor of the dependent VT schedule failed to emerge in DeCarlo's procedure.

DeCarlo's (1985) procedure can be adapted to the income-level manipulations used in the present report. If, for example, session length were shortened in the DeCarlo procedure, income maximizing predicts that subjects should defend their food intake by increasing their preference for the dependent VT schedule. Were such an increase to occur, it could not be the result of feedback-function differences between schedules because both schedules are time based, and with VT schedules responding does not occur to either schedule. Such an outcome would remove the alternative account of our effect described above and suggests that the changes in preference in Experiments 1 and 2 should be attributed to income-level maximizing.

EXPERIMENT 3

In this experiment, we adopted the design outlined above except that dependent and independent VI schedules were used instead of VT schedules. Response-dependent (i.e., VI) schedules were used to increase the likelihood that subjects would attend to the vertical slit on the work key that was used to cue the passage of session time. Because both schedules were time based (i.e., VIs) and differed only in when they operated, the changes in the marginal reinforcement rates produced by changes in response rate should be the same for both schedules. If income maximizing governs choice

in this procedure, preference for the dependent VI schedule should increase when session length is decreased.

METHOD

Subjects and Apparatus

Four adult White Carneau pigeons began the experiment at their free-feeding weights. All birds had substantial and varied experience responding to different schedules of reinforcement.

The apparatus was the same as that used in Experiment 2 except the right houselight was illuminated blue.

Procedure

Each session began with the illumination of the left and right keys with white light, and, with equal likelihood, illumination of the left green houselight or right blue houselight. When the blue houselight was illuminated, a VI 40-s schedule reinforced right-key responses. This schedule operated only while the blue houselight was lit. When the green houselight was illuminated, a second VI 40-s schedule that operated regardless of the schedule chosen reinforced right-key responses. Each left-key response switched the schedule in effect on the right key and the color of the houselight illumination. A COD was not in effect during this experiment. All other features of the procedure were the same as in the prior experiment.

Table 3 presents the order of experimental conditions and the number of sessions each subject was exposed to a condition. In the initial condition, session duration was 30 min, then 10 min, then 30 min, and was 10 min in the last condition. Each condition lasted at least 14 sessions and until choice proportions became stable for 3 consecutive days, based on experimenter judgment. Results are based on the mean of the last three sessions of each condition for each subject.

RESULTS

Table 3 also presents, for each schedule, subject, and condition, the local and overall response and reinforcement rates, changeover rate, and body weight. Local and overall rates of responding did not vary systematically with changes in session duration. Except for the initial exposure to the 10-min session condition

for Bird 34, changeover rates increased as session duration decreased; except for the 10-min session condition for Bird 32 and the replication of the 30-min session condition for Birds 33 and 34, overall reinforcement rate increased as session duration decreased. For all subjects, body weights increased as session duration increased.

Figure 4 presents the proportion of dependent-VI responding, time allocation, and reinforcement as a function of session duration for each subject and averaged across subjects. All birds tended to respond less, spend less time, and earn proportionally fewer reinforcers on the dependent VI schedule as session duration increased.

DISCUSSION

Income maximizing predicts that subjects experiencing a drop in the food earned on concurrent VR VI schedules will defend their intake by increasing their response rates on the VR schedule relative to the VI. Although the results of the first two experiments are compatible with this prediction, alternative choice models, such as matching, may also be capable of accommodating this outcome. If one posits that reducing access to food leads to a general increase in response rate, there should, by virtue of between-schedule feedback-function differences, be more additional VR reinforcers than VI reinforcers. According to matching theory, this increase in relative VR reinforcement should produce a shift in preference toward the VR—the very result we interpret as demonstrating income maximizing.

The present experiment circumvented this problem by presenting an income-maximizing test on dependent versus independent VI schedules. This schedule pair reproduces the aspect of concurrent VR VI schedules critical to their use as a test of income maximizing— that one schedule operates only when it is selected and the other operates regardless of the locus of choice—and provides the same feedback function for each choice alternative. As a consequence of this latter feature, changes in overall response rate do not produce between-schedule differences in reinforcement rate. Therefore, accounts such as matching do not predict a particular change in relative response rate if manipulating within-session income levels produces a change in overall rates of responding. However, income maximizing does

Table 3

Summary data: means and standard error of the means (in parentheses) over last three sessions for each condition and number of sessions and order of conditions.

Subject	Session duration (min)	Responses/min Local Dep VI	Responses/min Local Ind VI	Responses/min Overall	Responses/min Change-overs	Reinforcers/min Local Dep VI	Reinforcers/min Local Ind VI	Reinforcers/min Over-all	Body weight (g)	Number of sessions	Order
31	10	43.3 (1.4)	79.1 (3.8)	71.5 (2.4)	7.4 (0.9)	1.6 (0.1)	2.4 (0.7)	1.7 (0.9)	426 (3.8)	15	2
	10[a]	37.1 (2.1)	46.2 (1.5)	42.8 (1.0)	10.6 (1.4)	1.3 (0.1)	2.3 (0.1)	1.9 (0.1)	365 (2.4)	15	4
	30	30.8 (4.4)	71.5 (6.0)	69.9 (6.2)	2.0 (0.6)	1.5 (0.5)	2.1 (0.6)	1.5 (0.1)	543 (1.8)	22	1
	30[a]	32.0 (2.7)	87.7 (2.3)	83.2 (2.7)	2.8 (0.5)	1.6 (0.0)	2.0 (0.5)	1.6 (0.0)	511 (2.2)	17	3
32	10	19.5 (4.1)	38.4 (0.4)	37.7 (0.4)	0.6 (0.2)	1.3 (0.1)	3.5 (0.3)	1.4 (0.1)	382 (14.4)	18	2
	10[a]	46.9 (17.5)	51.4 (1.7)	51.9 (2.2)	0.1 (0.0)	1.2 (0.6)	1.6 (0.1)	1.6 (0.1)	335 (1.5)	18	4
	30	12.9 (6.5)	23.3 (4.9)	22.8 (5.2)	0.5 (0.3)	1.5 (0.1)	1.6 (0.7)	1.5 (0.1)	508 (4.4)	14	1
	30[a]	16.9 (1.2)	23.3 (1.4)	23.3 (1.3)	0.2 (0.1)	0.0 (0.0)	1.5 (0.0)	1.5 (0.0)	449 (2.2)	14	3
33	10	54.6 (16.7)	40.4 (2.9)	47.5 (7.3)	22.7 (1.0)	1.4 (0.1)	2.3 (0.1)	1.9 (0.1)	436 (1.8)	14	2
	10[a]	55.6 (2.9)	34.4 (0.4)	44.4 (1.4)	22.3 (1.0)	1.3 (0.0)	2.5 (0.2)	1.9 (0.1)	391 (1.5)	17	4
	30	41.2 (1.4)	34.4 (1.1)	36.1 (1.1)	13.0 (0.8)	1.6 (0.0)	1.5 (0.1)	1.6 (0.0)	488 (0.9)	25	1
	30[a]	57.5 (1.0)	44.0 (3.9)	48.0 (2.6)	19.7 (0.8)	1.4 (0.3)	2.1 (0.0)	1.9 (0.1)	496 (4.7)	17	3
34	10	33.3 (2.7)	41.7 (1.8)	37.6 (1.9)	8.0 (1.8)	1.3 (0.0)	2.5 (0.1)	1.9 (0.0)	433 (1.0)	16	2
	10[a]	38.0 (1.0)	42.2 (2.1)	40.3 (1.6)	10.3 (1.5)	1.3 (0.0)	2.7 (0.1)	2.1 (0.0)	446 (0.3)	17	4
	30	21.4 (1.2)	25.3 (2.9)	24.4 (2.5)	9.1 (1.2)	1.4 (0.1)	1.8 (0.0)	1.7 (0.0)	523 (0.9)	22	1
	30[a]	24.1 (1.3)	24.0 (1.6)	24.0 (1.5)	7.7 (0.7)	1.4 (0.3)	2.0 (0.1)	1.9 (0.1)	534 (2.7)	15	3

[a] Replication.

predict this change: Increasing session duration should result in a decrease in preference for the dependent VI schedule relative to the independent VI schedule. This was the result obtained.

Finally, the results are consistent with those of Experiments 1 and 2 in showing that income maximizing can be only a partial account for choice on concurrent VR VI schedules. The problem, shown clearly in the mean data, is that preferences for the dependent VI were less than for the independent VI. Yet, were income maximizing the sole process governing choice, short session durations should uni-

formly result in strong preferences for the dependent schedule.

GENERAL DISCUSSION

The economic thesis that organisms behave so as to maximize utility subject to constraints is not universally accepted among behavior analysts. One reason for skepticism is empirical: Herrnstein and Heyman (1979) found that pigeons failed to maximize their rates of reinforcement when choosing between concurrently available VR and VI schedules. If one equates reinforcement-rate maximizing with

utility maximizing, then pigeons are not utility maximizers.

The present report begins by assuming that pigeons are utility maximizers, but that what they maximize is not the rate of reinforcement but aggregate amount of reinforcement. Because sessions ended after 60 reinforcers in the Herrnstein and Heyman (1979) procedure, and animals were kept at a constant body weight across sessions and conditions, choice did not affect aggregate food consumption. Absent the opportunity to maximize food income, pigeons chose in accordance with other, subsidiary choice rules.

In the present report, we made two changes in the Herrnstein and Heyman (1979) procedure to ensure that choice could affect total food intake. First, pigeons earned their entire daily food ration during the experiment; second, sessions ended as a function of time. With these two changes, pigeons could regulate their food intake by adjusting their relative VR response rates. If hopper access time was reduced by shortening the hopper cycle (Experiment 1) or the duration of the session (Experiments 2 and 3), pigeons could compensate for their food loss by increasing their response rate, especially to the VR (Experiments 1 and 2) or increasing time allocation to the dependent VI (Experiment 3). That this tendency was evident in all three experiments and in those of Sakagami et al. (1989) suggests that income maximizing contributes to the control of choice as long as subjects are given the opportunity to demonstrate this fact.

Although the operation of an income-maximizing process is apparent in the results of this study, it offers an incomplete account of choice on concurrent VR VI schedules because the inverse relation between income level and VR preference was typically too small to maximize income or defend body weight completely. Hence, some other processes must also contribute to the determination of choice on this procedure.

For some, matching theory might be a likely candidate. Certainly the general conformity of the data in the present study with the predictions of the matching equation endorses its consideration. However, we oppose such a view for two reasons. First, matching theory is silent about whether choice should change as income level is changed. Even if we assume that matching tendencies should oppose those of
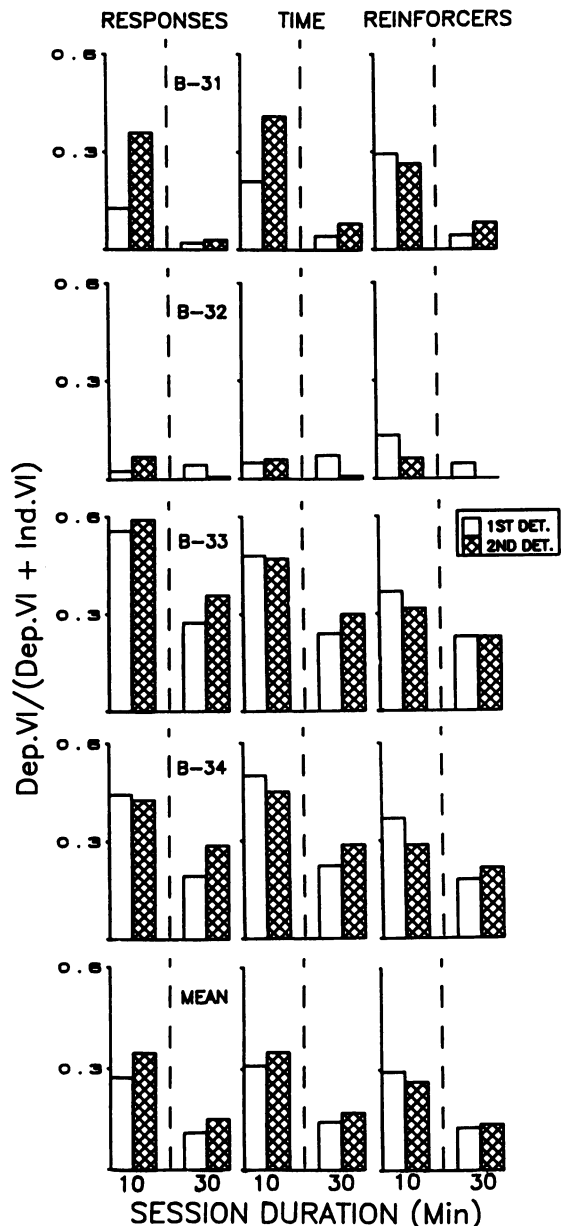

Fig. 4.   Relative rate of dependent VI responding (left column), time allocation (center column), and reinforcement (right column) for each subject (top four rows) and averaged across subjects (bottom row) as a function of session duration conditions. First and second determinations for each condition are represented by open and cross-hatched bars, respectively.

income maximizing (an assumption that may account for the incomplete income-maximizing effect), we would also have to assume that the strength of this opposition grows as income

level decreases. Such a set of assumptions is clearly ad hoc.

A second difficulty in using matching theory to explain the results of our study relates to the fact that the evidence for a matching process on concurrent VR VI schedules is suspect. As noted by Ziriax and Silberberg (1984), the tendency for reinforcement rates to track response rates on VR schedules often produces matching outcomes across a wide range of choice ratios on concurrent VR VI schedules. This tendency is also evident in the present report. For example, in the last phase of Experiment 1, we see approximate matching in Birds 0 and 1. Yet the percentages of their responses to the VR schedule were, respectively, 70% and 30%. These matching outcomes despite discrepant choice ratios show that, at least on some occasions, reinforcer ratios track response ratios. Hence, matching outcomes in this study may be more a reflection of each schedule's reinforcement feedback function than of a matching process controlling choice.

An account we favor is based on the idea that income maximizing is tempered by a strong preference for immediate reinforcement. A property of VI schedules is that assigned reinforcers await a response. In consequence, long stay times on the VR schedule will result in that schedule having a lower local probability of reinforcement than is available on the VI. If pigeons switch to the VI prematurely to obtain this higher local reinforcement likelihood, then they would fail to maximize their total food intake (Silberberg & Ziriax, 1982). In this case, income maximizing fails as a unitary account of choice, although it remains possible that pigeons are also maximizing some dimension of the time stream of reinforcement (Silberberg, Warren-Boulton, & Asano, 1988). This assumption leads to a two-factor maximizing account in which income level (within-session reinforcement) and income flow (time stream of reinforcement) jointly determine choice.

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